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The format of children's mental images: Evidence from mental scanning

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Abstract

This study examined the development and format of children's mental images. Children (4-, 5-, 6-7-, 8-9-, and 11-year-olds) and adults ($N = 282$) viewed a map of a fictitious island containing various landmarks and two misleading signposts, indicating that some equidistant landmarks were different distances apart. Five-year-olds already revealed the linear time-distance scanning effect, previously shown in adults (Experiments 1 and 2): They took longer to mentally scan their image of the island with longer distances between corresponding landmarks, indicating the depictive format of children's mental images. Unlike adults, their scanning times were not affected by misleading top-down distance information on the signposts until age 8 (Experiment 1) unless they were prompted to the difference from the outset (Experiment 2). Findings provide novel insights into the format of children's mental images in a mental scanning paradigm and show that children's mental images can be susceptible to top-down influences as are adults'.

Keywords: Cognitive development, mental imagery, image scanning, format, visuo-spatial processes

Mental imagery is ubiquitous in children's and adults' every-day life. The theoretical consensus over decades is that our mental images are depictive in format (*depictive theory*: Kosslyn, 1981; Kosslyn et al., 2003). Apart from evidence from mental rotation (Estes, 1998; Frick, Daum, Walser, & Mast, 2009; Frick, Möhring, & Newcombe, 2014; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Marmor, 1975), there is limited research on the format of children's mental images. This research examines children's imagery format in mental scanning and how it is affected by knowledge.

Several studies have demonstrated that adults take longer to scan a mental image with more distant to-be-scanned-objects (e.g., Beech, 1979; Borst & Kosslyn, 2008; Borst & Kosslyn, 2010; Borst, Kosslyn, & Denis, 2006; Finke & Pinker, 1983; Iachini & Ruggiero, 2010; Kosslyn, Ball & Reisser, 1978). Specifically, adults' mentally scan between landmarks on a previously presented island map in a time linear with landmarks' distances (Kosslyn et al., 1978). These findings demonstrate that mental images incorporate the metric information present in the original object or scene, indicating their depictive format (Denis & Kosslyn, 1999; Kosslyn et al., 2003).

Adults' performance on these tasks is penetrable by top-down influences such as verbal codes. Scanning times are influenced by misleading mileage signs indicating different distances between equidistant landmarks (Richman, Mitchell & Reznick, 1979). Thus, mental scanning performance is cognitively penetrable by top-down factors, that is, the semantic content of participants' beliefs and goals (see Pylyshyn, 2003). The fact that 5-year-olds visual perceptual processes are influenced by top-down processes (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011) would suggest top-down influences on their mental imagery. To our knowledge this has not been examined to date.

Evidence of the depictive format of children's mental images comes mainly from mental rotation. Five- to 6-year-old children's response time, like adults', increases linearly

with increasing rotation angle between objects (e.g, Estes, 1998; Frick, et al., 2009; Frick, et al., 2014). Moreover, 6-year-olds describe their mental rotation performance in mental state terms, whereas the minority of 4-year-olds does (Estes, 1998). That is, introspection into your own mental states allows mental rotation. This raises the possibility that introspective ability gives rise to knowledge penetrating mental images. Indeed, children's use of metacognitive strategies and insight undergoes significant developments between 4 and 8 years (Bjorklund & Douglas, 1997; Flavell, Green, & Flavell, 2000; Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011; Perner, Kloo, & Rohwer, 2010; Schneider, 1986; but see Balcomb & Gerken, 2008; Call & Carpenter, 2001 for 2-3-year-olds showing already implicit monitoring abilities). Thus, one might expect top-down knowledge guiding imagery to be evident at 5 years.

To examine the format of children's and adults' mental images we adapted Kosslyn et al.'s (1978) "island task." Participants mentally scanned between landmarks of a previously presented island map image. Additionally, we examined how distance information on a map (top-down knowledge) affects its representation. For example, if one distance between landmarks is labelled as further away on a signpost (5 footsteps) than another (1 footstep), will it take children longer to mentally scan although the distances are the same (see Richman et al., 1979 for adult findings)? Do children show the typical time-distance linear relation (taking linearly longer to mentally scan between further apart to-be-scanned items), suggesting their mental images preserve metric distance. Additionally, we ask at what age children's mental images become penetrable to top-down information as adults. If children preserve metric distance in their mental images but their scanning is influenced by top-down factors then this strongly favours the idea that children's mental images are depictive in form while influenced by conceptual factors.

Experiment 1

Method

Participants

Overall 152 participants (76 females) participated: 24 4-year-olds ($M = 60$ months, range = 54-65), 26 5-year-olds ($M = 71$ months, range = 66-77), 26 6-year-olds ($M = 83$ months, range = 78-89), 25 8-year-olds ($M = 107$ months, range = 99-113), 25 11-year-olds ($M = 132$ months, range = 126-137) and 26 adults ($M = 21$ years, range = 19-31). In both experiments children were recruited from local schools and adults via the university sign-up system receiving financial reimbursement.

Materials and procedure

A map of a fictitious island (see Kosslyn et al., 1978; Richman et al., 1979) was presented on a standard 17.3 inch laptop screen, containing a Lighthouse, Volcano, Hut, Pond and Tree (Figure 1). Two signposts pointed between the Lighthouse-Volcano and the Hut-Volcano (both of which were equal distances), adapted from the 20- and 80-mile ones used by Richman et al. (1979) to be suitable for 4-5-year-olds: one signpost showed 1 footstep and the number 1, the other 5 footsteps and the number 5. Sign post positions were counterbalanced between the two landmark pairs between participants.



Figure 1. *Island map with landmarks and signposts.*

Participants, tested individually, saw ‘Percy the Pirate Parrot’ walk across a map of a park. On 3 practise trials, participants closed their eyes and, on the experimenter’s ‘Start’ command, imagined Percy walking between specified landmarks, and said ‘Stop’ when he had arrived at the second landmark. After each imagery attempt they watched Percy walking between said landmarks, were asked to compare this to how they imagined him walking, and given further instruction if necessary. In imagery trials participants viewed the island for 45 seconds. They named and memorised everything on it. After 45 seconds landmarks disappeared leaving an empty island. Participants used the mouse to drag and drop each landmark and the two signposts into their correct position on the island. Once a landmark was within a 30 pixel radius of its correct location it shifted and locked into place.

The island then disappeared. Participants closed their eyes and imagined the island with Percy standing at the Lighthouse and then walking between landmarks in the following order (actual distances in parentheses): Lighthouse-Tree (262mm), Lighthouse-Volcano (81mm), Lighthouse-Pond (154mm), Lighthouse-Hut (70mm), Hut-Lighthouse (70mm), Hut-Pond (100mm), Hut-Volcano (81mm), Hut-Tree (260mm). The computer recorded the time taken to mentally scan between each of the landmark pairs.

Finally, participants completed 'perception control' trials, where this process was repeated, but with the island visible on the screen. Participants were instructed to follow their eyes between the landmarks to imagine Percy walking between them. After the experiment participants were asked what the signs meant and which sign represented further.

Results and Discussion Experiment 1

Across both experiments Bonferroni confidence interval adjustments and post-hoc analyses were used. Outlier response times that were 2 standard deviations from the mean per distance and age group were removed.

Preliminary analyses

Whether the signposts pointed up or down had no effect. The four participants who were incorrect about the signposts' meaning were excluded from the signpost analysis.

Mental imagery scanning times over different distances

To control for any effects of the signposts on the time-distance linear relation, the two distances (both 81mm) which had a signpost between each of them were excluded from this analysis.

Scanning times increased linearly with increasing distance for all age groups (all R^2 s $> .03$, $ps < .05$) (Table 1).

Table 1

Mental image scanning task: Overall mean scanning times and association of actual distance and scanning times for each age group in Experiment 1.

Age group	4-year-olds	5-year-olds	6-year-olds	8-year-olds	11-year-olds	Adults
Mean (SD)	7165 (4534)	8194 (3756)	10583 (5838)	10264 (5122)	11555 (4264)	10307 (2488)
Intercept	5385	4077	6815	5254	6093	3944
β	.17	.41	.27	.42	.52	.73
T	2.06	5.55	3.54	5.56	7.42	13.17
P	= .04	< .001	< .001	< .001	< .001	< .001

Note. β = standardized beta.

However, for the 4-year-olds this relation was due to a large increase in scanning times between similar distances 260mm (hut-tree) and 262mm (lighthouse-tree), whilst there was no increase between other distances (Figure 2). After removing scanning times for the 262mm distance, 4-year-olds showed no time-distance linear relation. The model remained significant for all older age groups (all R^2 s > .07, ps < .005).

To examine the trajectory of the time-distance-scanning relation across age, we calculated the slopes of the best fitting lines (i.e., scanning rates) for each participant, and then submitted these slopes to a one-way ANOVA. Slopes differed between age groups, $F(5, 146) = 4.36$, $p < .001$, $\eta p^2 = .13$. Four-year-olds' slopes ($B = 11.66$ ms/mm) were less steep than 8- ($B = 32.78$ ms/mm), 11-year-olds' ($B = 35.78$ ms/mm) and adults' ($B = 41.51$ ms/mm) (all $ps < .05$). There were no further slope differences (5-year-olds: $B = 26.97$ ms/mm; 6-year-olds: $B = 24.69$ ms/mm, suggesting that the scanning time-distance linear relation did not change from age 5 onwards.

In perception control, all ages showed a linear time-distance relation (all R^2 's > .08, F s > 11.46, p s < .001).

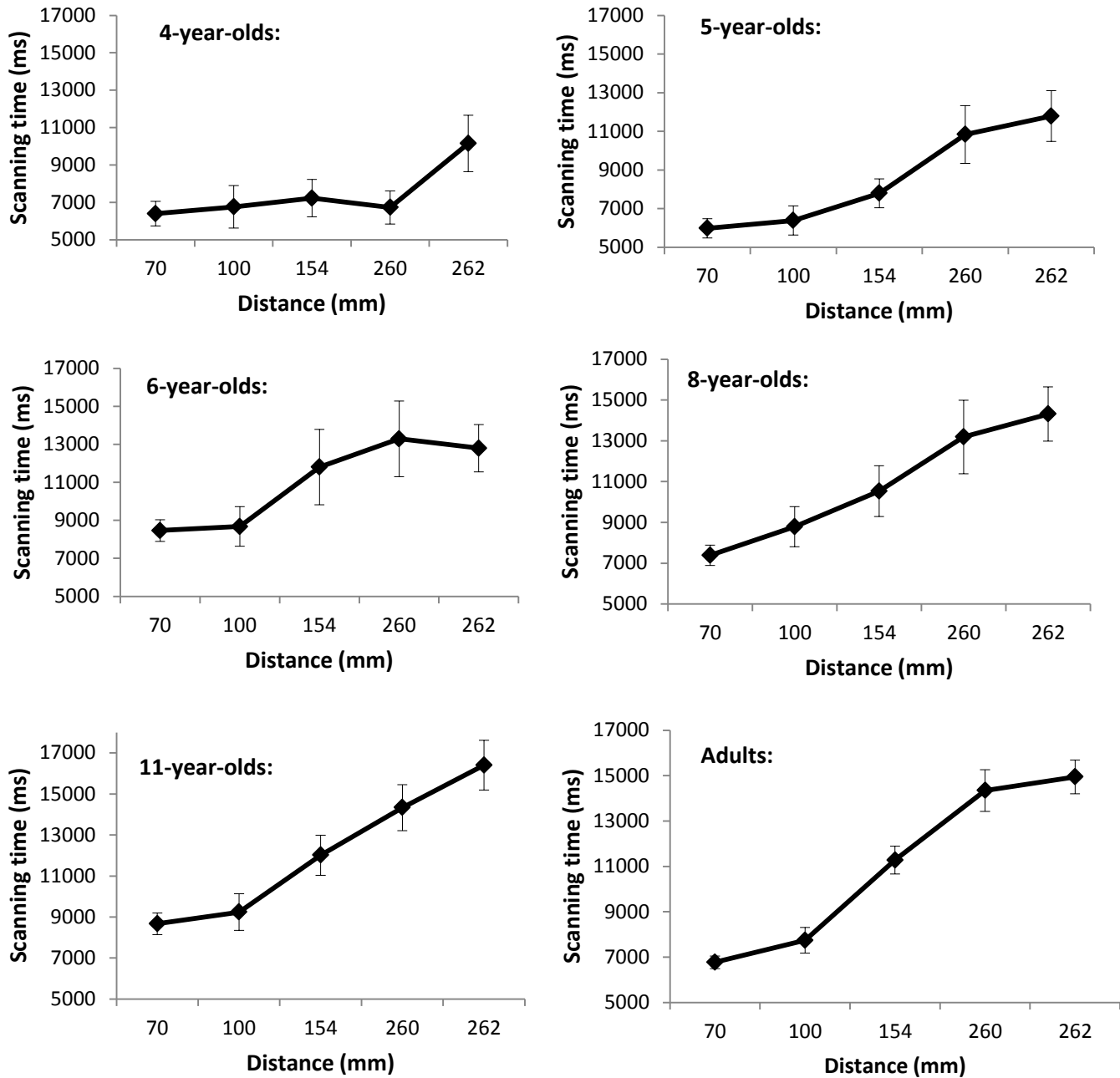


Figure 2. Time to scan the different distances for each age group in Experiment 1

Effect of signposts on scanning times

A 2 (sign: 1 vs. 5 footsteps) x 6 (age) mixed ANOVA revealed a main effect of sign, $F(1, 142) = 4.51, p = .04, \eta p^2 = .03$. Participants showed longer scanning times for the 5 footsteps sign ($M = 7841, SD = 4453$) than the 1 footstep sign ($M = 7265\text{ms}, SD = 3959$). There was no age effect, $F(5, 142) = 1.08, p = .382, \eta p^2 = .04$, but a sign x age interaction, $F(5, 142) = 2.40, p < .05, \eta p^2 = .08$. Only 8-, 11-year-olds and adults showed longer scanning times for the 5 footsteps sign than the 1 footstep sign, whilst 4-, 5- and 6-year-olds showed no difference (Table 2). Thus, children younger than 8 years were not affected by the misleading signpost information, despite understanding what it meant. In contrast, 8-year-olds' and older children's scanning times were affected by the misleading signpost information, indicating that their mental imagery performance is affected by top-down influences, a phenomenon previously found in adults (Richman et al., 1979).

Table 2

Mean scanning times for each age group for each of the distances showed by the 1 and the 5 footsteps signposts in Experiment 1.

Age group	4-year-olds	5-year-olds	6-year-olds	8-year-olds	11-year-olds	Adults
1 footstep	7500	6696	7801	7510	7947	6175
Mean (SD)	(4938)	(4411)	(4335)	(4139)	(3307)	(2327)
5 footsteps	6708	6230	8371	8524	9263	7795
Mean (SD)	(5547)	(4033)	(5023)	(5047)	(3895)	(2201)

Findings of Experiment 1 revealed that successful scanning emerged between 4 and 5 years. This first demonstration of a linear time-distance relation in children's mental images

in a scanning paradigm supports the notion that mental images are depictive in nature, already evident in 5-year-old children.

To check that linear scanning effects reflect children preserving metric properties, scanning effects should be absent when participants are not required to scan. Therefore, in Experiment 2 a 'Rapid Verification task' was implemented (Kosslyn et al., 1978), requiring participants to decide whether two landmarks were present rather than to scan between them.

The second aim of Experiment 2 was to examine why children younger than 8 years were not affected by the misleading signposts. They may understand the nature of signpost information but not use this information spontaneously in a scanning task, or have difficulty thinking simultaneously about the signposts and the distance information. Prompting was used to examine these possibilities.

Experiment 2

Method

Participants

There were 130 participants (73 females): 27 5-year-olds ($M = 65$ months, range = 58-73), 27 7-year-olds ($M = 87$ months, range = 75-93), 26 9-year-olds ($M = 114$ months, range = 107-126), 25 11-year-olds ($M = 137$ months, range = 128-141), and 26 adults ($M = 37$ years, range = 20-70). The children were in the same school years as their age counterparts in Experiment 1.

Materials and Procedure

The materials and procedure were exactly the same as in Experiment 1 with three exceptions. The signpost conceptual question was posed before the imagery trials, a 'Rapid Verification task' was added, and a signpost recall phase was implemented.

Island Scanning. During the 45 second island study and landmark naming period, participants were explicitly prompted towards the difference in signpost length by asking the

conceptual check question, what each signpost meant and which one was further. The remaining procedure was the same as before.

Rapid Verification. This followed the island task. Participants heard 10 pre-recorded word pairs (two practice trials, eight experimental trials). The first word in each pair was always a landmark present on the map (e.g., hut). The second word was either a landmark also on the map (e.g., pond), or *not* on the map (e.g., waterfall). Participants viewed the island for 45 seconds, then closed their eyes and imagined the island. They heard the first word (“hut”) and instructed to imagine it. Then they heard a second word (“pond”) and reported as quickly as possible whether the item was on the island or not. Immediately, after the participants’ answer, the naïve experimenter pressed the according button on the laptop, indicating a 'yes' or 'no' response.

Signpost Recall. Finally participants were shown an image of the two signposts side by side with the number and footsteps removed.

Results and Discussion Experiment 2

Preliminary analyses

Participants ($N = 17$) who were incorrect about what the signposts meant, or the numbers on them, were excluded.

There were no effects of the positions of the signposts (pointing up or down).

Mental imagery scanning times over different distances

Scanning times increased linearly with increasing distance for all age groups (all R^2 s $> .08$, $ps < .001$) (Table 3).

Table 3

Mental image scanning task: Overall mean scanning times and association of actual distance and scanning times for each age group in Experiment 2.

Age group	5-year-olds	7-year-olds	9-year-olds	11-year-olds	Adults
Mean (SD)	6071 (4175)	8585 (4025)	10644 (2736)	13658 (5987)	12813 (4342)
Intercept	2661	6173	7221	8541	4992
β	.35	.28	.46	.34	.65
T	4.32	3.40	6.08	4.10	9.08
P	< .001	< .001	< .001	< .001	< .001

Note. β = standardized beta.

The mean slopes differed between age groups (Figure 3), $F(4, 112) = 7.19, p < .001$, $\eta p^2 = .21$. Adults' slopes ($B = 50.21$ ms/mm) were steeper (all $ps < .002$) than the three youngest age groups' (5-year-olds: $B = 18.23$ ms/mm; 7-year-olds: $B = 19.43$ ms/mm; 9-year-olds: $B = 22.22$ ms/mm) who did not differ (all $ps > .99$). Ten-year-olds' slopes ($B = 35.97$ ms/mm) did not differ from the other ages (all $ps > .13$) (Table 3).

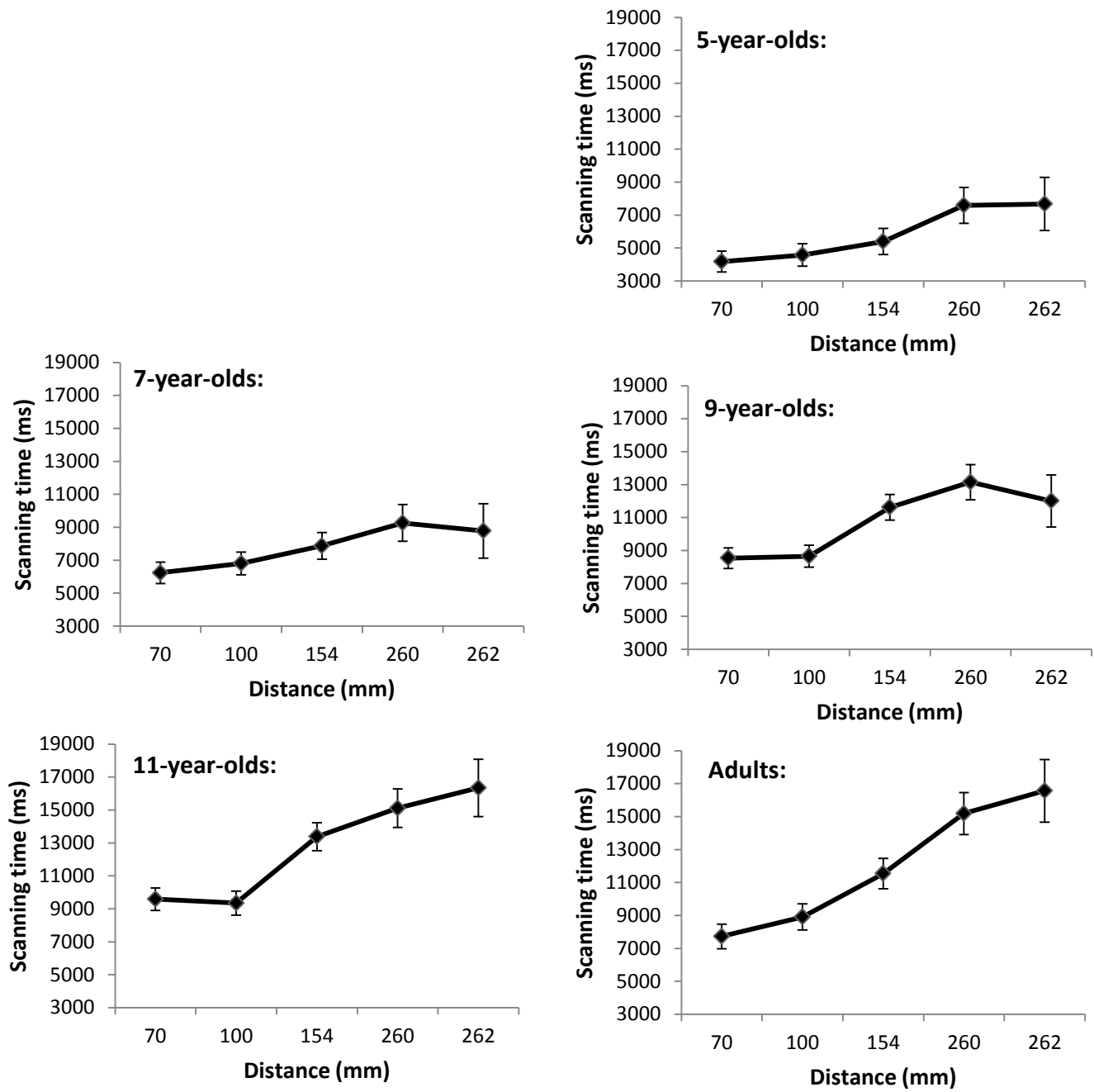


Figure 3. Time to scan the different distances for each age group in Experiment 2

For perception control trials, all ages showed a linear time-distance relation (all R^2 s > .08, F s > 12.27, p s < .001).

Effect of signposts on scanning times

A 2(sign: 1 vs. 5 footsteps) x 5(age) mixed ANOVA revealed an effect of sign, $F(1, 71) = 21.00$, $p < .001$, $\eta p^2 = .23$. Participants showed longer scanning times for the 5 footsteps sign ($M = 7686$, $SD = 3383$) than the 1 footstep sign ($M = 6176$ ms, $SD = 2128$). There was an effect of age, $F(4, 71) = 8.96$, $p < .001$, $\eta p^2 = .34$, where 5-year-olds scanned equally fast as 7-year-olds but faster than 9-, 11-year-olds and adults (all p s < .004) (Table 4). Additionally 7-year-olds scanned faster than adults ($p = .01$).

Table 4

Mean scanning times for each age group for each of the distances showed by the 1 and the 5 footsteps signposts in Experiment 2.

Age group	5-year-olds	7-year-olds	9-year-olds	11-year-olds	Adults
1 footstep	4337	5341	7285	7141	7773
Mean (SD)	(1920)	(1615)	(2076)	(1327)	(914)
5 footsteps	5653	6953	8787	8226	10090
Mean (SD)	(3497)	(3131)	(2617)	(2494)	(3817)

Rapid verification

Accuracy. All age groups performed at ceiling in verifying whether a landmark was present or not, therefore, no further statistical analyses were conducted.

Response Time. There were no linear increases in verification times with increasing distance in the four present landmark pairs for any age group (all R^2 s < .15, p s > .14).

Overall, as in Experiment 1 participants from age 5 showed a linear increase in scanning times with increasing distance, suggesting that when children and adults scan a scene they preserve metric properties in their mental images. Consistent with this, the linear time-distance effect disappeared when the task did not require scanning (rapid verification). Findings across both experiments indicate that children's mental images are depictive, previously only documented in scanning tasks with adults (e.g., Borst & Kosslyn, 2010).

In contrast to Experiment 1, with prompting about difference in signpost distances before the imagery trials, even 5- to 8-year-olds' scanning times were affected by misleading signpost information: They had no difficulty thinking simultaneously about signposts and distance.

General Discussion

This first study examining the format of children's mental images in a mental scanning paradigm shows that by age 5 children show the time-distance scanning effect previously observed in adults, indicating that they represent mental images depictively. This converges with research on mental rotation (Estes, 1998; Frick, et al., 2009; Frick et al., 2014; Kosslyn, et al., 1990; Marmor, 1975) and spatial scaling (Möring, et al., 2014), supporting the notion that young children preserve spatial properties in their mental image.

That the 4-, but not the 5-year-olds, failed to show a linear-time distance relation (Experiment 1) indicates that the ability to scan mental images undergoes rapid developments around this age. This youngest age group perhaps had difficulty holding the island map in mind whilst scanning, and would show subsequent improvements in related cognitive processes such as visual working memory (Riggs, et al., 2006), memory for spatial locations (Plumert & Spencer, 2007), coding distance in spatial navigation tasks (Bullens, et al., 2010), and the ability to scale distances (Frick & Newcombe, 2012; Möring, et al., 2014). The

developmental cognitive mechanisms underlying why 4-, but not 5-year-olds' scanning performance is poor is an interesting avenue for future research.

While children showed a linear time-distance relation from age 5, their imagery performance was also susceptible to top-down influences such as misleading distance markers when prompted towards the distance difference (Experiment 2). Thus, at 5-years mental images are penetrated by knowledge as previously found in visual perceptual phenomena such as ambiguous stimuli (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011). Without prompts, by age 8 children were affected by misleading markers (Experiment 1), spontaneously using conceptual information in their mental imagery. This converges with developments in metacognitive strategies and insight that develop during this age range (e.g., Flavell, et al., 2000; Ghetti, et al., 2011). For example, 5-year-olds are less able to introspect into their thought processes than 8-year-olds (Flavell et al., 2000) and 6-year-olds are less able to assess their subjective experience of recollecting details of events than 9-year-olds (Ghetti et al., 2011). Consistent with this, current findings show that 5-year-olds are less likely than 8-year-olds to spontaneously use top-down knowledge to guide their imagery.

In sum, this research provides novel findings on children's scanning abilities, indicating 5-year-olds preserve metric properties in their mental images as adults do; the age at which their mental images also begin to be influenced by top-down processes.

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